MODELLING AND SIMULATION OF SKYHOOK CONTROLLER FOR SEMI-ACTIVE SUSPENSION SYSTEM

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ABSTRACT

The purpose of this project is to modeling and simulates the skyhook controller for semi-active suspension system for a quarter car model. There are two parts to be developed in this study namely, the hydraulic model and force tracking controller. The simulation of this system will be determined by performing computer simulations using the MATLAB and SIMULINK toolbox. The data for each parameter were obtained from the research that have done previously. The simulation results show that the semi-active suspension system could provide significant improvements in the ride quality and road handling compare with the passive suspension system.

ABSTRAK

Tujuan dari projek ini adalah untuk pemodelan dan simulasi pengatur skyhook yang diubahsuai untuk sistem suspensi aktif untuk model suku kereta. Ada dua bahagian untuk dikembangkan dalam kajian ini iaitu, model hidraulik dan pengatur penjejak paksaan. Simulasi sistem ini akan ditentukan dengan melakukan simulasi komputer dengan menggunakan MATLAB dan aturcara SIMULINK. Data untuk setiap parameter yang diperolehi dari kajian yang telah dilakukan dahulu. Keputusan simulasi menunjukkan bahawa sistem suspensi aktif dapat memberikan penambahbaikan yang signifikan dalam kualiti pemanduan dan pengendalian jalan berbanding dengan sistem suspensi pasif.

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ABBREVIATIONS

2DOF	Two degree of freedom
MR	Magneto-rheological
$\boldsymbol{C_{SKY}}$	Skyhook controller

CHAPTER 1

INTRODUCTION

1.1 Project background.

Suspension on the vehicle is a component equipment not only functions as a shock absorber of vibrations resulting from the burden of the vehicle and the wheel contact with the road surface, but also as a driving stability control made on a straight road driving, while taking turns, and driving on the road surface not smooth.

Nowadays many suspension manufacturers made their design from result of studies on the existing suspension and improvement have been made to the ability of suspension for passenger comfort in vehicles. Returning to the original purpose of the installation of suspension in a vehicle is to give comfortable to the passengers. When the vehicle is being driven wheel rotating in contact with the road surface and this depends on the type of surface. This phenomenon will result in vibration in direct proportion to the surface and the weight of the burden. Vibration is then absorbed by the suspension system consisting of a spring and damper. Spring will be oscillates when received vibrations from damper produced. Spring will return to the initial position so that oscillation will be smaller and smaller. In other words the resulting vibrations will be felt, but the amount is less than the actual vibration.

Various types of shock absorbers are sold in the market depend on the type of use such as Tanabe, Apex, HKS and many more. It's also equipped with a variable adjustment is made of alloys. It not only became one of the basic components of a vehicle but had to be madness on the user to modify their suspension systems for ride comfort.

Three types of suspensions that will be reviewed here are passive, fully active, and semi-active suspensions. A conventional passive suspension is composed of a spring and a damper. The suspension stores energy in the spring and dissipates energy through the damper. Both components are fixed at the design stage. For this reason, this type of suspension falls victim to the classic suspension compromise.

If the damper is replaced with a force actuator, the suspension becomes a fully active suspension. Hindered by its complexity and its power Consumption, fully active suspensions have yet to be accepted for conventional use. The idea behind fully active suspensions is that the force actuator is able to apply a force to the suspension in either jounce or Rebound. This force is actively governed by the control scheme employed in the suspension. Several different control schemes will be discussed later.

The third and final type of suspension that will be mentioned here is a semi-active suspension. In a semi-active suspension, the passive damper is replaced with a semi-active damper. A semi-active damper is capable of changing its tangent characteristics. Whether through mechanically changing orifices or fluid with adjustable viscosity a semi-active damper offers greater variation in close proximity. Again, the control algorithm used in the design governs the amount of damping

1.2 Problem Statement.

Vehicle suspension absorbs vibrations generated when the wheel in contact with the road surface is different and it gives effect to the vehicle passenger comfort. Control and vibration effects produced depend on the weight of the vehicle load and road surface if the amount of vibration generated can be controlled and reduced then this would increase passenger comfort.

1.3 Objective of the Research.

In this research focus on reduces of the vibration produced by road profile to the suspension and control the impact.

The objectives are:

1. To develop a two degree of freedom (2 DOF) quarter model passive suspension system diagram using Simulink software.
2. To develop Magneto-Rheological (MR) damper model using Bing-Ham method.
3. To develop skyhook controller to semi-active quarter car suspension with Magneto-Rheological (MR) damper using Simulink software.

1.4 Scope of Work.

Scopes of this project are:

1. Modelling 2DOF quarter car model for passive suspension system diagram using Simulink software.
2. Modelling Bingham method with MR damper diagram using Simulink software.
3. Modelling Skyhook controller for Bingham method with MR damper diagram using Simulink software.
4. Connect the entire diagram then run the simulation and compare the result between passive suspension system and semi-active suspension system using Bingham method.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction.

In this chapter will discuss on the suspension system including the types of suspension system. First of the system is passive, then the second one is semi-active suspension this kind of suspension is more cheep then the passive. The third system is active suspension system. Description of the MR damper and the Skyhook controller are also described in this chapter.

2.2 Overview of Vehicle Suspension system

The suspension system also includes shock and/or struts, and sway bars. Back in the earliest days of automobile development, when most of the car's weight (including the engine) was on the rear axle, steering was a simple matter of turning a tiller that pivoted the entire front axle. When the engine was moved to the front of the car, complex steering systems had to evolve. The modern automobile has come a long way since the days when "being self-propelled" been enough to satisfy the car owner. Improvements in suspension and steering, increased strength and durability of components, and advances in tire design and construction have made large contributions to riding comfort and to safe driving.

The suspension system has two basic functions, to keep the car's wheels in firm contact with the road and to provide a comfortable ride for the passengers. A lot of the system's work is done by the springs. Under normal conditions, the springs support the body of the car evenly by compressing and rebounding with every up-and-down movement. This up-and-down movement, however, causes bouncing and swaying after each bump and is very uncomfortable to the passenger. These undesirable effects are reduced by the shock absorbers.

Suspension is the term given to the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. Suspension systems serve a dual purpose – contributing to the car's handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations. These goals are generally at odds, so the tuning of suspensions involves finding the right compromise. The suspension also protects the vehicle itself and any cargo or luggage from damage and wear. The design of front and rear suspension of a car may be different.

2.3 Types of Suspension System

In generally suspension system can be dividing on two, passive and active system. The active suspension can be future classified into two types: a semi-active system and a fully active system according to the control input generation mechanism (Appleyard and Wellstead, 1995). The semi-active suspension system uses a varying damping force as a control force. For example, a hydraulic semi-active damper varies the size of an orifice in the hydraulic flow valve to generate desired damping force.

2.3.1 Passive Suspension System

The mass-spring-damper parameters are generally fixed, and they are chosen based on the design requirements of the vehicles. The suspension has ability to store energy in the spring and dissipate it through the damper. When springs support a load, it will compress until the force produced by the compression is equal to that of the load on it. If some other force then disturbs the load, then the load will oscillate up and down around its original position for some time.

Conventional or passive suspension systems are designed as a compromise between ride comfort and handling performance (Thompson, 1971). Ride is primarily associated with the ability of a suspension system to accommodate vertical inputs. Handling and attitude control relate more to horizontal forces acting through the centre of gravity and ground-level moments acting through the wheels. A low bounce frequency for maximum ride comfort normally leads to a low pitch frequency.

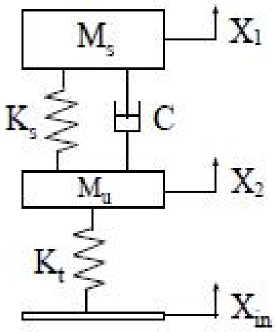

Figure 2.1: Passive Suspensionn system

Source: Cristoper A.P (1998)

2.3.2 Semi-Active Suspension System

Semi-active or adaptive systems are terms usually used to describe suspension systems that have some form of intelligence in the suspension dampers. Typically the damping curves can be altered such that the wheel control over the range of inputs is maximized. These systems also require fast-acting devices and complex control algorithms. A semi active suspension has the ability to change the damping characteristics of the shock absorbers without any use actuators. Previously, for semi-active suspension, by utilizing the controlled dampers under closed loop the regulating of the damping force can be achieved (Williams, 1994).

Semi-active suspension system using solenoid is the most economic and basic type of semi-active suspensions. They consist of a solenoid valve which alters the flow of the hydraulic medium inside the shock absorber, therefore changing the dampening characteristics of the suspension setup. The solenoids are wired to the controlling computer, which sends them commands depending on the control algorithm. This type usually called "Sky-Hook" technique.

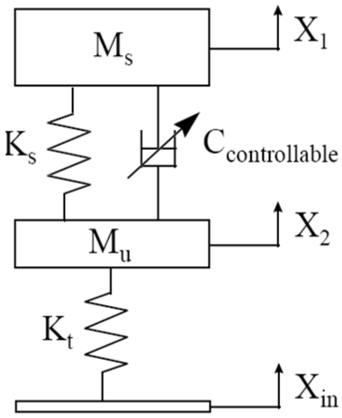

Figure 2.2: Semi-Active Suspension System

Source: Cristoper A.P (1998)

2.3.3 Active Suspension System

Active suspension system is one in which the passive components are augmented by hydraulic actuators that supply additional force. Theoretically this means that the compromise in conventional suspension systems can be eliminated. The active suspension is characterized by the hydraulic actuator that placed parallel to the damper and spring. It also can control both wheel hop motion as well as body motion. It can improve the ride comfort and ride handling simultaneously. (Sam, 2006).

The drawbacks of this design are high cost, added complication/mass of the apparatus needed for its operation, and the need for rather frequent maintenance and repairs on some implementations. Active suspension systems, however, usually involve a continuous power requirement, fast-acting devices, complex control algorithms, and closed-loop control systems. The cost of these systems has limited their application on mass-produced vehicles.

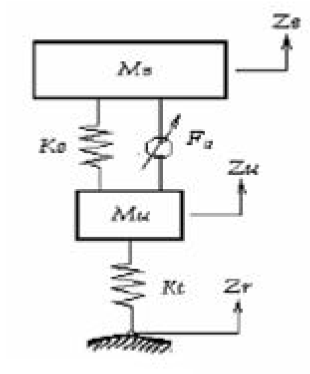

Figure 2.3: Active Suspension System
(Sam, Y.M and Huda, K. (2006))

2.4 Magneto-Rheological (MR) Damper

A magneto-rheological damper or magneto-rheological shock absorber is a damper filled with magneto-rheological fluid, which is controlled by a magnetic field, usually using an electromagnet. This allows the damping characteristics of the shock absorber to be continuously controlled by varying the power of the electromagnet. This type of shock absorber has several applications, most notably in semi-active vehicle suspensions which may adapt to road conditions, as they are monitored through sensors in the vehicle, and in prosthetic limbs.

MR dampers are much like conventional fluid dampers in basic construction, but the conventional damper valves are replaced with an electromagnetic coil to control the MR fluid behaviour.

Linear MR dampers can be of three primary designs: monotube, twintube, ordouble-ended (also known as through-tube). The three design types reflect methods of adjusting the fluid volume to account for the volume of the damper shaft. Monotube designs are the most common damper design; they exhibit simplicity and compactness of design and with the ability to be mounted in any orientation.

The monotube damper is composed of a main damper housing, a piston and piston rod assembly, and an accumulator, as shown in Figure. The main reservoir contains the piston and piston rod assembly submersed in the MR fluid, while the accumulator reservoir contains a compressed, non-oxidizing gas (usually nitrogen). As the piston rod moves into the damper housing, a volume of fluid equivalent to the volume of the intruding piston rod is displaced. The accumulator piston moves toward the bottom of the damper, compressing the nitrogen charge to account for the change in volume. As the piston rod retracts, the accumulator piston moves up the damper tube to counteract the loss of volume. The monotube damper design is the most versatile damper design since it can be mounted in any orientation without affecting the damper's performance.

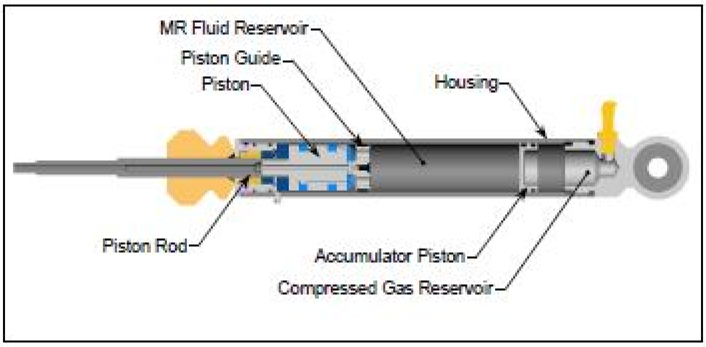

Figure 2.4: Sectional view of MR damper built by James Poynor (2001).

The twintube damper uses inner and outer cartridges to negotiate the changing volume of MR fluid, as shown in Figure 2.8. As the piston rod enters the inner housing, the extra volume of MR fluid displaced by the piston rod is forced from the inner housing to the outer housing via the foot valve. When the piston rod retracts, MR fluid flows back into the inner housing, therefore preventing the creation of vacuum in the inner housing and cavitations of the damper. Drawbacks of this design include size and orientation – this damper must be mounted with the foot valve at the bottom to ensure no cavitation.

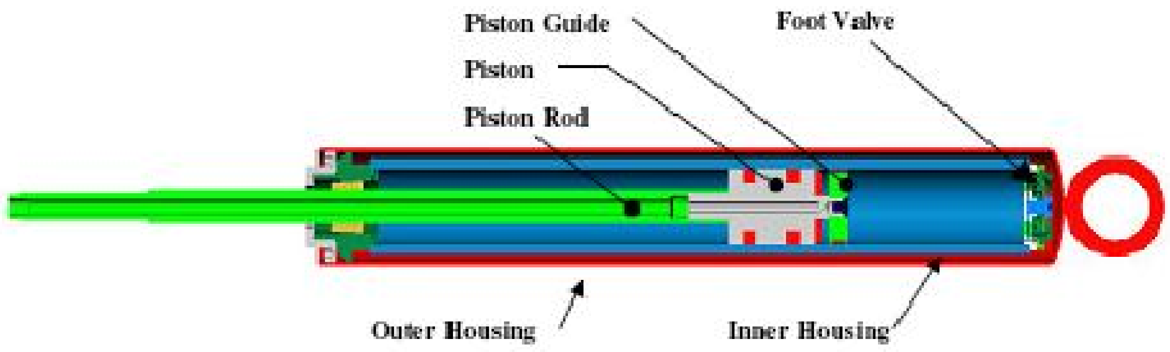

Figure 2.5: Twintube MR Damper, Section View (Poynor J. C, 2001)

Double-ended (through-tube) dampers use a third method to account for the piston rod volume. Fully extended, the piston rod protrudes through both sides of the damper housing, as shown in Figure. This method of damper design retains a constant piston rod and fluid volume within the housing, thereby eliminating the need for a second housing or accumulator.

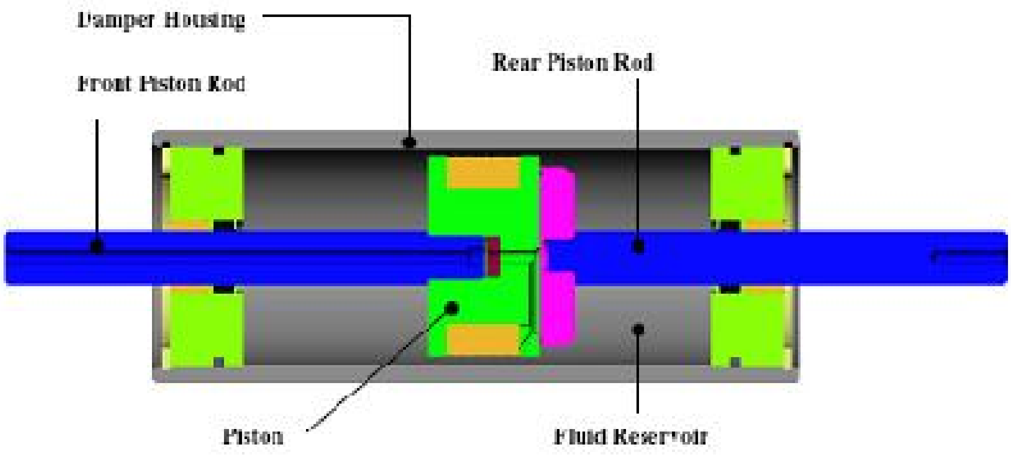

Figure 2.6: Double-Ended (Through-Tube) MR Damper, Section View (Poynor J. C, 2001)

The twintube and double-ended damper provide a significant advantage over the monotube design. The pressurized charge in the accumulator of the monotube design adds a spring force to the damping rod, so not only does the damper have force vs. velocity characteristics, it also has a spring rate. The twintube and double-ended damper, however, do not demonstrate this trait, showing only force vs. velocity characteristics.

2.4.1 Magneto-Rheological Fluid

In recent year, a family of fluids known as magneto-rheological fluids has gained increased recognition for its many applications. Magneto-rheological fluid or as known as MR fluids, demonstrate a change in apparent viscosity when exposed to the magnetic field. Jacob Rainbow, an inventor at the US National Bureau of Standards, developed the first MR fluids in the late 1940s.

Upon introduction, there was keen interest in technology for the devices like automatic transmissions and clutches, but the activity dropped off shortly thereafter. Resurgence in interest in MR fluids occurred in the early 1990s when Dave Carlson of Lord Corporation began to experiment with the fluids for the variety of devices, including vehicle suspensions.

Jacob Rainbow’s original MR fluids consisted of nine parts by weight of carbonyl iron to one part of carrier fluid, namely silicon oil hydrocarbon-based oil. To increase the fluid stability and reduce settling, grease or another thixotropic solution was added. This original solution proved to be as strong as modern day MR fluids. Modern fluids use micron sized iron particles coated with an anticoagulant in a carrier fluid of hydrocarbon-based oil, silicon-based, or water. The fluids also contain a number of anti-settling agents to prevent the fluid from hardening.

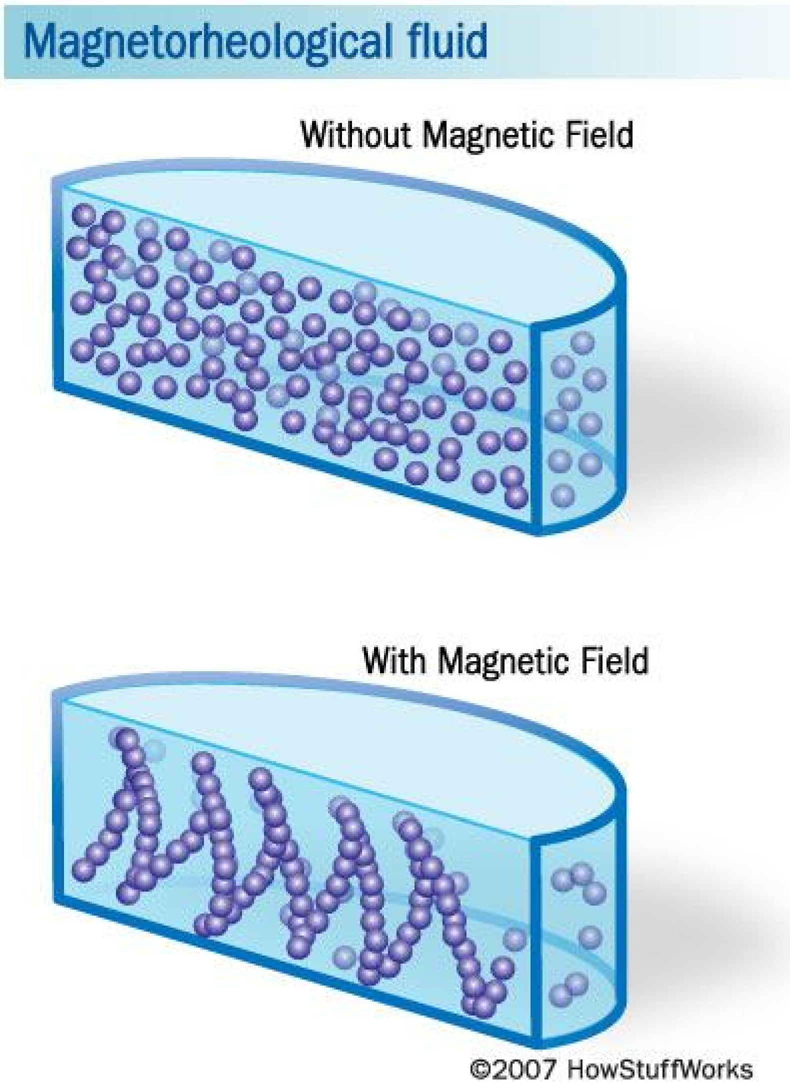

Figure 2.7: Magneto-Rheological Fluid (How Stuff Works 2007)

Magneto-rheological fluids are materials that exhibit a change in rheological properties (elasticity, plasticity, or viscosity) with the application of a magnetic field. The MR effects are often greatest when the applied magnetic field is normal to the flow of the MR fluid. Another class of fluids that exhibit a rheological change is electro-rheological (ER) fluids. As the name suggests, ER fluids exhibit rheological changes when an electric field is applied to the fluid. There are, however, many drawbacks to ER fluids, including relatively small rheological changes and extreme property changes with temperature.

Although power requirements are approximately the same, MR fluids only require small voltages and currents, while ER fluids require very large voltages and very small currents. For these reasons, MR fluids have recently become a widely studied 'smart' fluid. Besides the rheological changes that MR fluids experience while under the influence of a magnetic field, there are often other effects such as thermal, electrical, and acoustic property changes. However, in the area of vibration control, the MR effect is most interesting since it is possible to apply the effect to a hydraulic damper. The MR fluid essentially allows one to control the damping force of the damper by replacing mechanical valves commonly used in adjustable dampers. This offers the potential for a superior damper with little concern about reliability, since if the MR damper ceases to be controllable, it simply reverts to a passive damper.

2.5 Skyhook Control

As the name implies, the skyhook configuration shown in the Figure below has a damper connected to the some inertial reference in the sky. With the skyhook configuration, the tradeoff between resonance control and high-frequency isolation, common in passive suspensions, is eliminated. Notice that skyhook control focuses on the sprung mass, as c_{sky} increases, the sprung mass motion decrease. This, of cause, comes with cost. The skyhook configuration excels at isolating the sprung mass from base excitations, at the expense of increased unsprung mass motion.

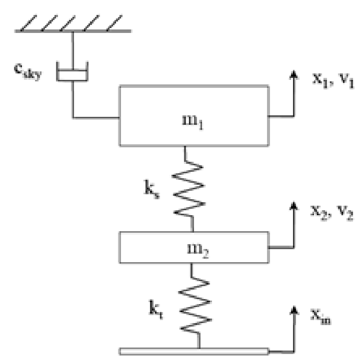

Figure 2.8: Skyhook controller diagram

Source: Goncalves. D.F (2001)

2.6 Bingham.

The stress-strain behavior of the Bingham viscoplastic model (Shames and Cozzarelli, 1992) is often used to describe the behavior of MR (and ER) fluids. In this model, the plastic viscosity is defined as the slope of the measured shear stress versus shear strain rate data. Thus, for positive values of the shear rate, γ· the total stress is given by:

Where $\tau_{y(field)}$, is the yield stress induced by the magnetic (or electric) field and η is the viscosity of the fluid. Based on this model of the rheological behavior of ER fluids, Stanway, *et al.* (1985, 1987) proposed an idealized mechanical model, denoted the Bingham model, for the behavior of an MR damper. The model consists of a Coulomb friction element placed in parallel with viscous damper as shown in Figure 2.9.

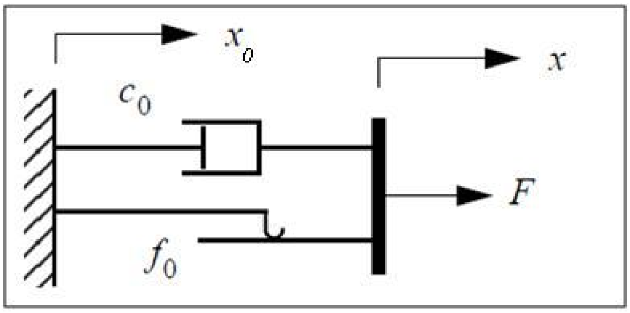

Figure 2.9: Bingham Model of a Controllable Fluid Damper

Source: Gongyu, Hiroshi and Yoshihisa (2000)